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High Data Rate Wireless Communication Networks for Navy and Marine Corps Applications

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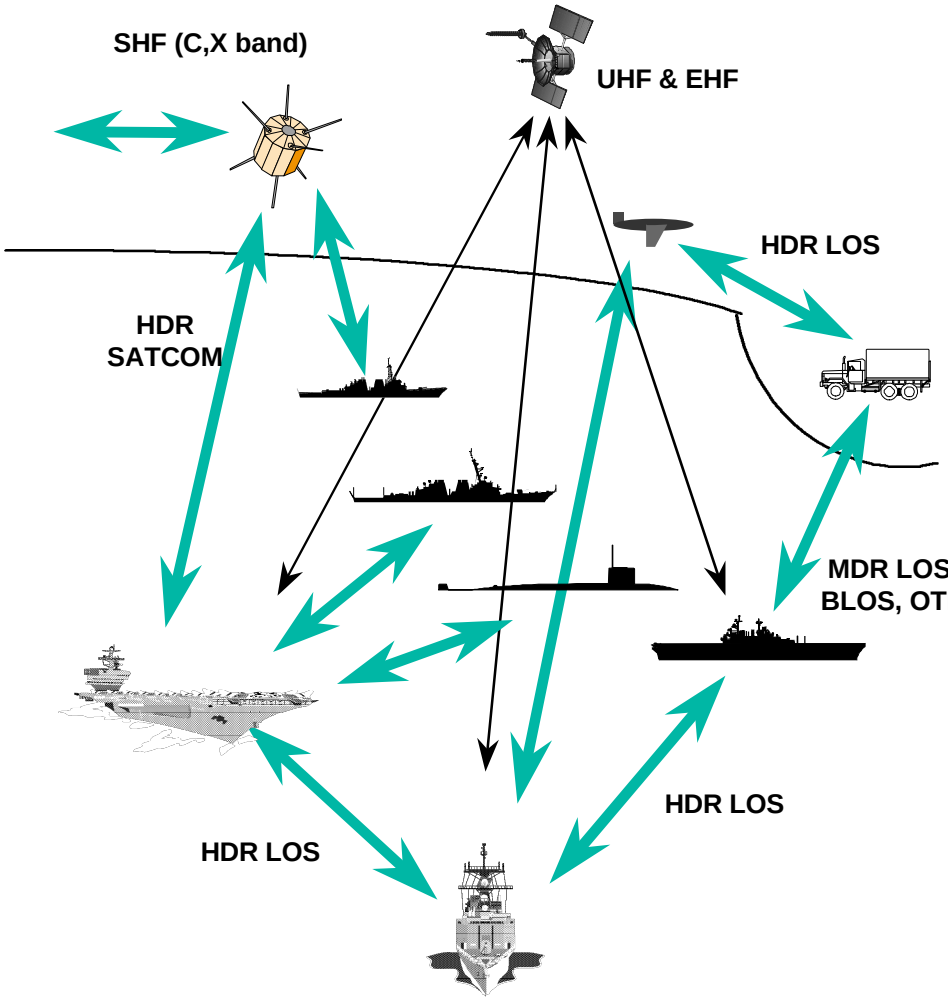
High Data Rate Wireless Communications Network



Goals

- allow for seamless flow of information (voice, data, video) among Naval ships, between services (Marines, Army, AF, Coast Guard), and shore based institutions
- maximize channel capacity (data rate*user/BW)
- automated relaying to extend LOS range
- self-configuring network to provide communication infrastructure to rapidly deployed shore forces
- combine HDR/MDR LOS, BLOS & SATCOM communication links into wireless network

Challenges

- present communication systems are severely capacity limited, fixed frequency, single purpose (“stove pipe”)
- mobility of nodes complicates networking both at RF and baseband (non-COTS feature)
- interoperability requires cooperation at radio, baseband switching/muxing, and application levels (can not afford to forget legacy systems)

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HDR LOS Wireless Network
Objectives

" Develop and Demonstrate new capabilities and technologies for insertion into JPO Joint Programmable Modular Communications System (JPMCS) "

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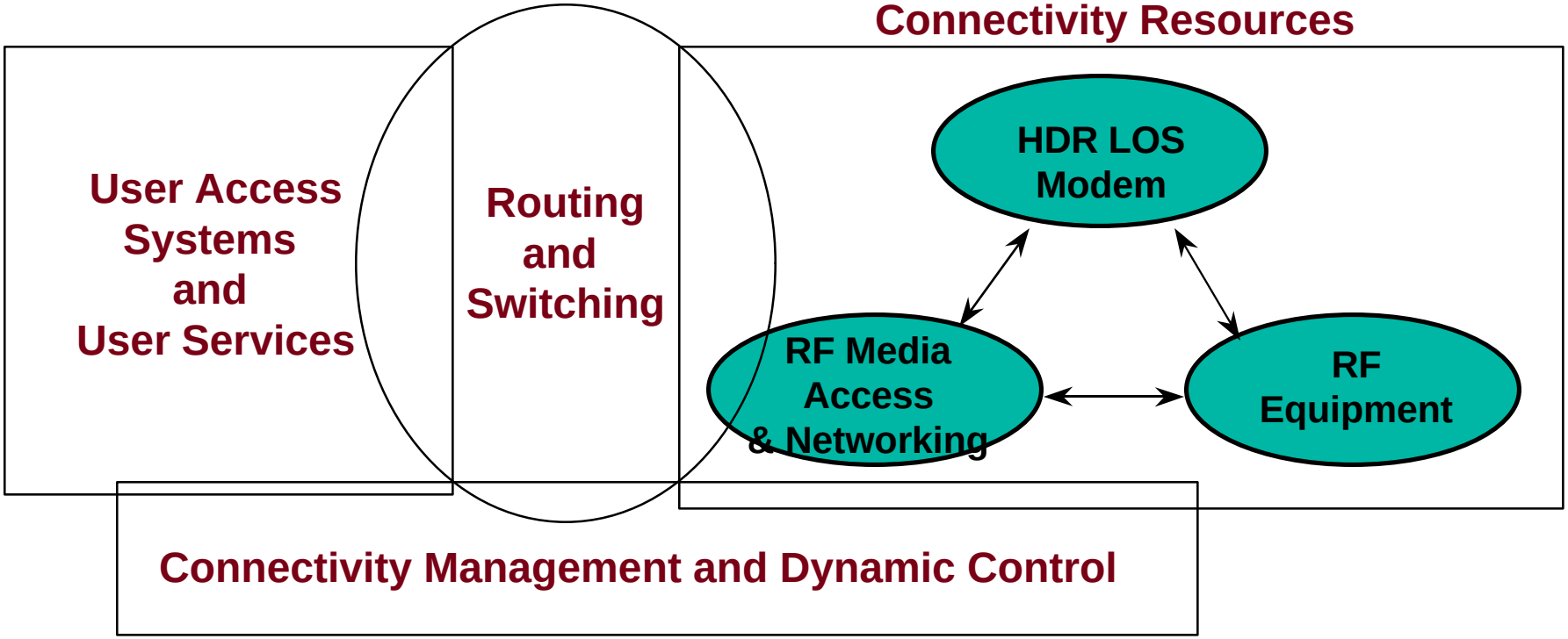
HDR Wireless Communications Network: Components



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HDR LOS Wireless Network
Approach

1. ONR (Gee/Madan/Gerr) sponsored 6.2 program (FY93-FY99)
   - Channel Estimation and Characterization
   - Modulation/Demodulation Techniques
     - Multichannel AEQ, OFDM, FEC, nonlinear compensation
   - Theoretical Performance Prediction
   - Equipment Development and Integration
     - AN/WSC-3 & CM701, MITEQ linear mixer
2. BAA: HDR LOS Radio for Mobile Maritime Communications
   - Two contracts awarded (phased approach to reduce risks)
     - NOVA Engineering, Cincinnati OH awarded in June '97
       - HDR LOS Modem based on OFDM
       - RF Equipment to support OFDM modem
     - ViaSAT Corp., Carlsbad CA awarded in Aug '97
       - HDR LOS Modem based on Equalized M-PSK/M-QAM
       - RF Equipment
       - RF MAC
       - System Integration of NOVA modem
   - Each contract has three Phases (Design, Prototype, Op. Test)

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RF Media Access Control

- simple point-to-point TDM/FDMA
  - dynamic frequency allocation and power control to increase # of users (eliminate dedicated spectrum)
  - presently used technique for 2-3 ships
  - does not scale well
- point-to-multipoint TDM/FDMA
  - NRL (Althouse et. al.) method for recent ATD (MCA)
  - simplifies hardware required (1 Tx, "*n*" Rx)
  - simplifies frequency allocation ($2\Sigma_{i=1}^{n}$ i -> *n*)
  - reduced system gain for simple control
- multi-carrier TDMA DAMA
  - voice, IP, and point-to-point links broken into LDR circuits then TDMA
  - allows for bandwidth on demand, relaying, multicasting, network expansion/contraction
  - scaleable to different size networks

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HDR LOS Modem

- **variable data rates to maintain reliable ship-to-ship/shore/air communication**
  - **range < 10nmi R=2.0+ Mbps in 600 KHz Channel**
  - **range < 15 nmi R=1.5 Mbps in 600 KHz Channel**
  - **range < 22 nmi R=576 kbps in 600 KHz Channel**
  - **range < 30 nmi R=64 kbps in 600 KHz Channel**
- **nx64 kbps / nx20 KHz 3dBBW - 25 KHz Channel**
- **Orthogonal Frequency Division Multiplexing**
  - **ease of implementation, robust to narrowband and impulsive interference, robust to multipath fading, COTS standards for ADSL, EU-BA and DTV**
- **Adaptive Equalized Single Carrier M-PSK/QAM**
  - **proven technology, can also be made robust to interference and multipath fading, rapid burst acquisitions**

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RF Equipment

- **High Power Amplifiers**
  - **reduce requirements for linearity to shrink size, weight, and cost**
  - **reduce number of transmissions to mitigate co-site problems (MAC, multiple receivers)**
  - **predistortion techniques to compensate for nonlinearities in amplifier or**
  - **constant modulus waveforms**
- **Couplers/ BPF**
  - **typically used as post-selector and pre-selector filters**
  - **present UHF coupler (OA/9123) weighs 250 lbs**
  - **need smaller, frequency agile, variable BW couplers**
- **Antennas**
  - **need multiple high gain Tx/Rx beams (“n”)**
  - **initialization with omnidirectional & GPS & ?**
  - **must allow for mobility**

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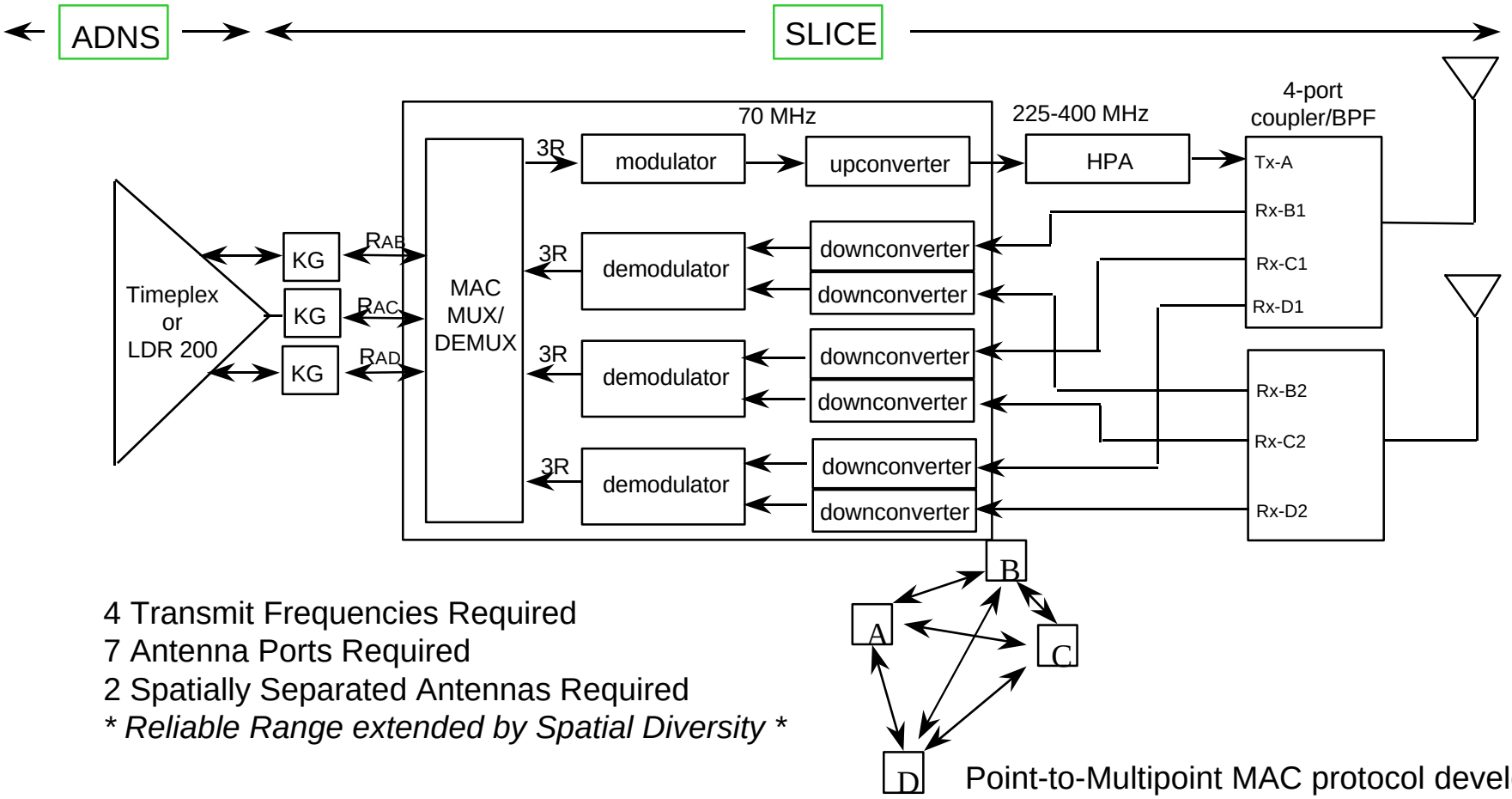
Example System Design

3 Full-Duplex Dedicated LOS Links (each with Spatial Diversity) off a single platform



4 Transmit Frequencies Required
7 Antenna Ports Required
2 Spatially Separated Antennas Required
** Reliable Range extended by Spatial Diversity **

Point-to-Multipoint MAC protocol developed at NRL (Althouse, et. al.) allows for 4 ships fully connected

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Extend LOS Range

- **Develop Automatic Relaying Capability**
  - **radio should be capable of installation in an airborne platform (Helicopter, P-3, UAV, etc)**
- **Develop MDR HF Capabilities**
  - **64-128 kbps using surface wave to 100 nmi or more**
  - **determine surface wave characteristics to optimize waveform (leverage off HDR LOS Links Project)**
- **Develop Point-to-Point OTH Capabilities**
  - **MDR/HDRs to 60 nmi or more using high gain directional antennas**
  - **need robust diversity combining techniques (spacial, frequency, temporal)**
  - **investigate dual use of shipboard stabilized antennas (ex: SPG-62 FCS work going on at NSWC Port Hueneme)**
  - **interoperability with U.S. Marine Corps and U.S. Army systems (TRC-170, HCTR, etc)**

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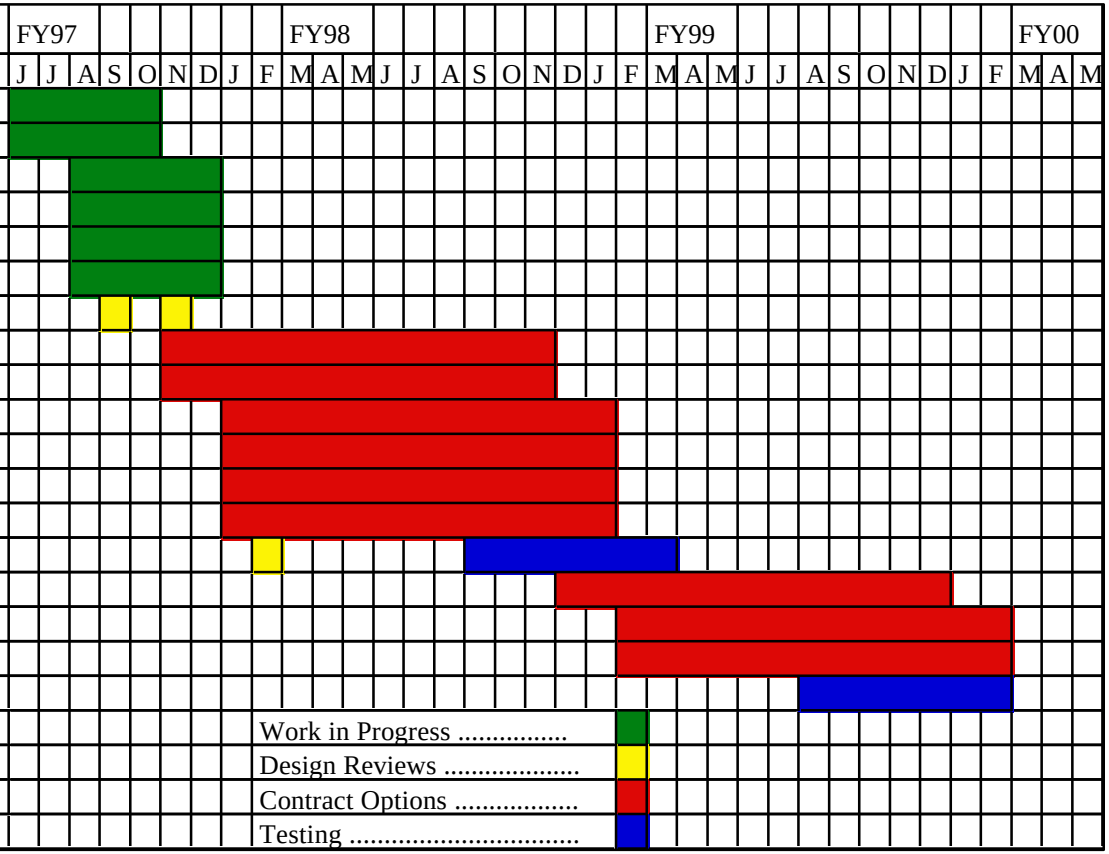
HDR LOS Radio
Contract Schedules

Contract Schedules			
Phase I	Nova	OFDM modem	
		R F	
	ViaSAT	M-PSK modem	
		R F	
		MAC	
		Integration	
Phase II	Nova	OFDM modem	
		R F	
	ViaSAT	M-PSK modem	
		R F	
		MAC	
		Integration	
Phase III	Nova	OFDM modem	
	ViaSAT	System w/ Nova modem	
		System w/ ViaSAT modem	



Phase I: Detailed Design and Tradeoff Studies
Phase II: Prototype Development and Test (at least 3 units)
Phase III: Fleet Operational Testing (up to 18 units)

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Backup Slides

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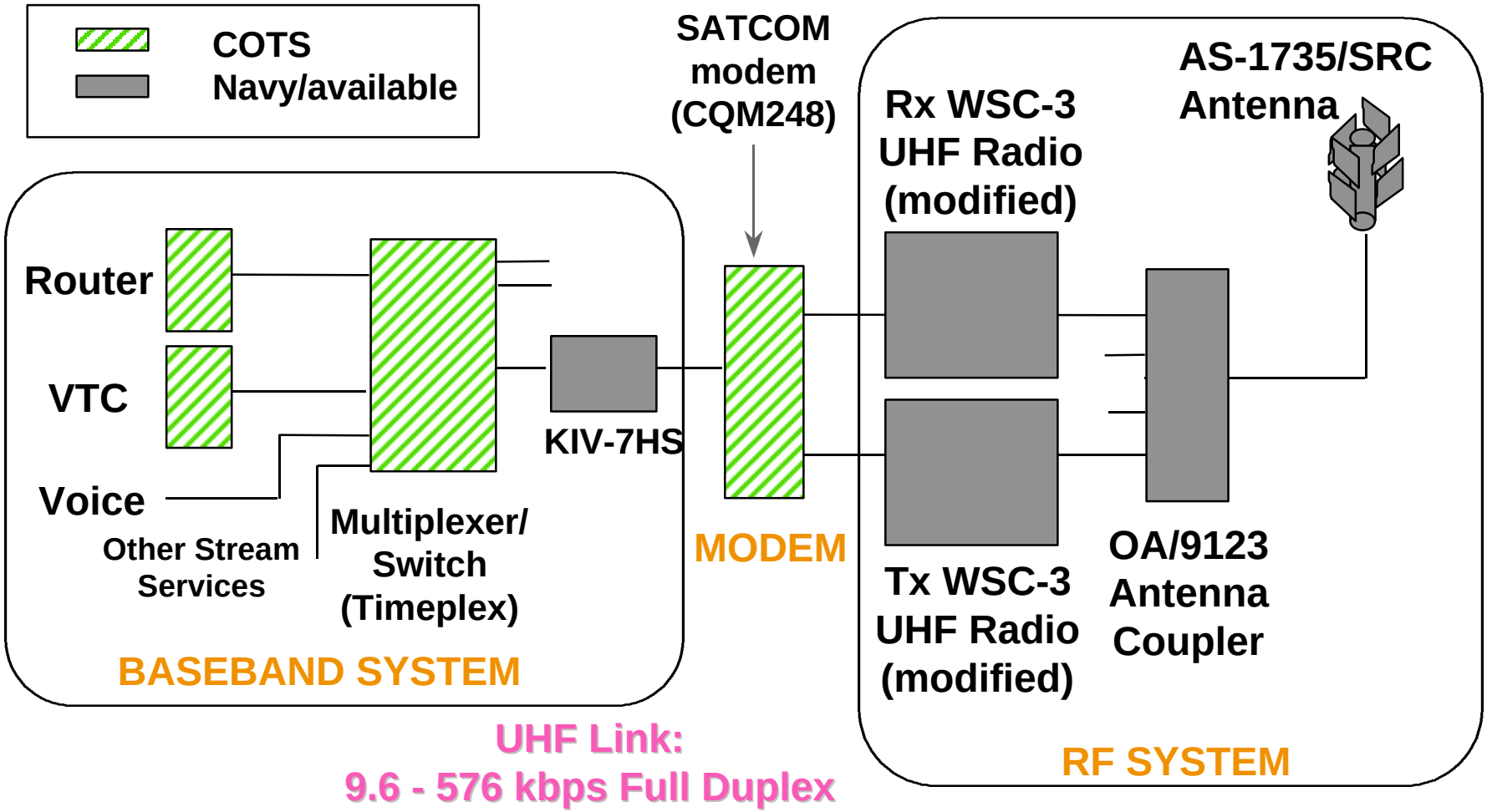
HDR LOS Radio
Equipment Development

- **MDR WSC-3s and CM701**
  - **simplex T1 link tested over water Q3 FY94**
  - **first ship board tests conducted on USS Rentz in Q4 FY94 (Sponsor: Lt. R. Stakelum, Cmdr. R. Johnson)**
  - **full duplex 384 kbps ship-to-shore link tested using phase 1 prototype equipment during Kernel Blitz in Q2 FY95 (Sponsor: ARPA via R. Glass)**
  - **USS Abraham Lincoln, USS Princeton, and USS John Paul Jones deployed with phase 1 prototype equipment Q2-Q4 FY95 (Sponsor: PMS400, Lt. R. Stakelum)**
  - **USS Boxer ARG Q2-Q4 FY97, USS Tarawa ARG Q1-Q3 FY98 (Sponsor: SPAWAR-176)**
- **MITEQ Upconverters/downconverters**
  - **4-5 dB system gain improvement w/ AR class AB PA**
  - **RF equipment ~$60K**
  - **mixers being used by ONI program**
- **BAA Contracts to develop “true” HDR LOS radio**
  - **prototypes during Q4-FY98 to Q1-FY99**
  - **fleet operation testing Q4-FY99 to Q1-FY00**

MDR UHF LOS Radio

WSC-3 w/ SATCOM modem ("UHF MDR")



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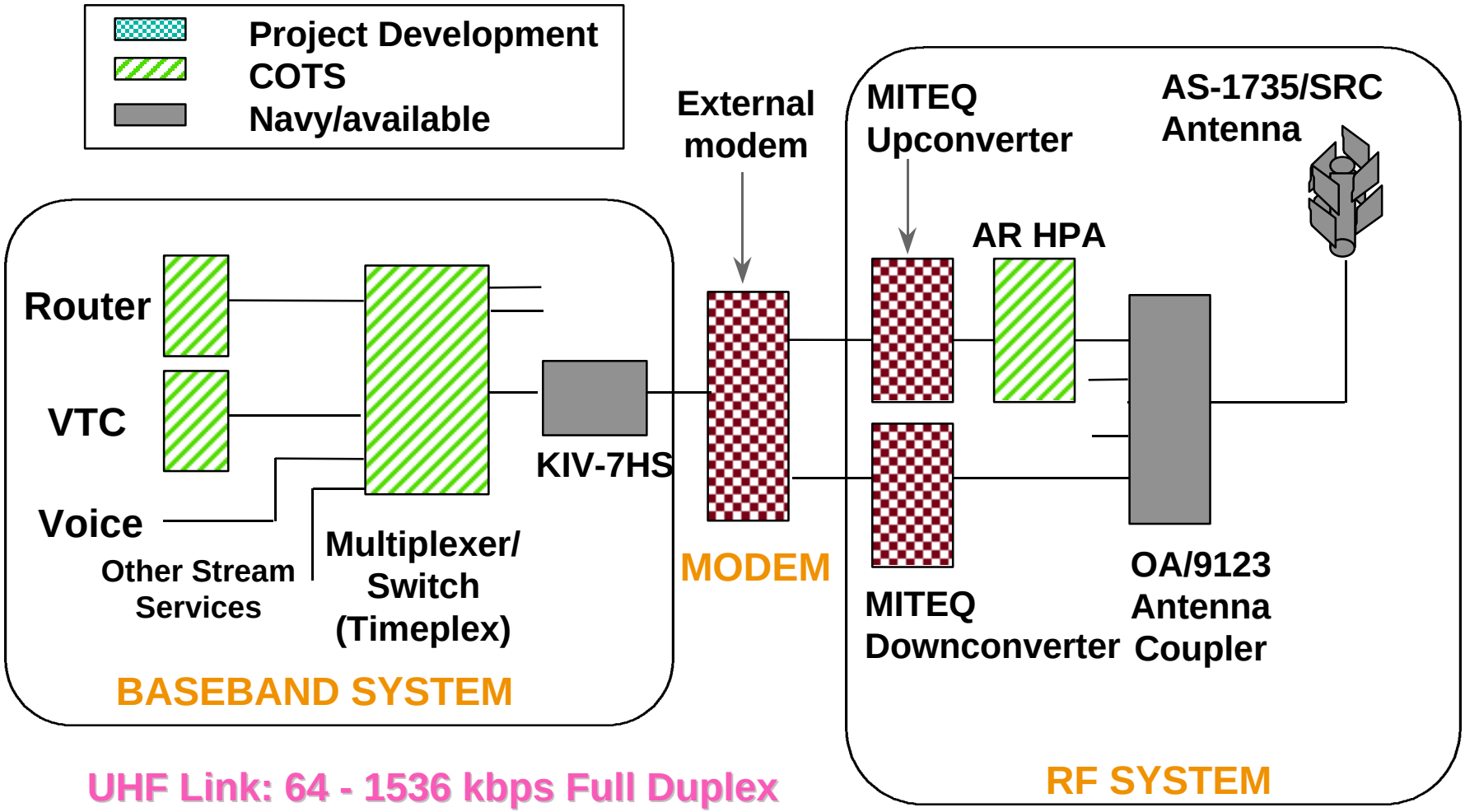
HDR UHF LOS Radio

MITEQ w/ external modem



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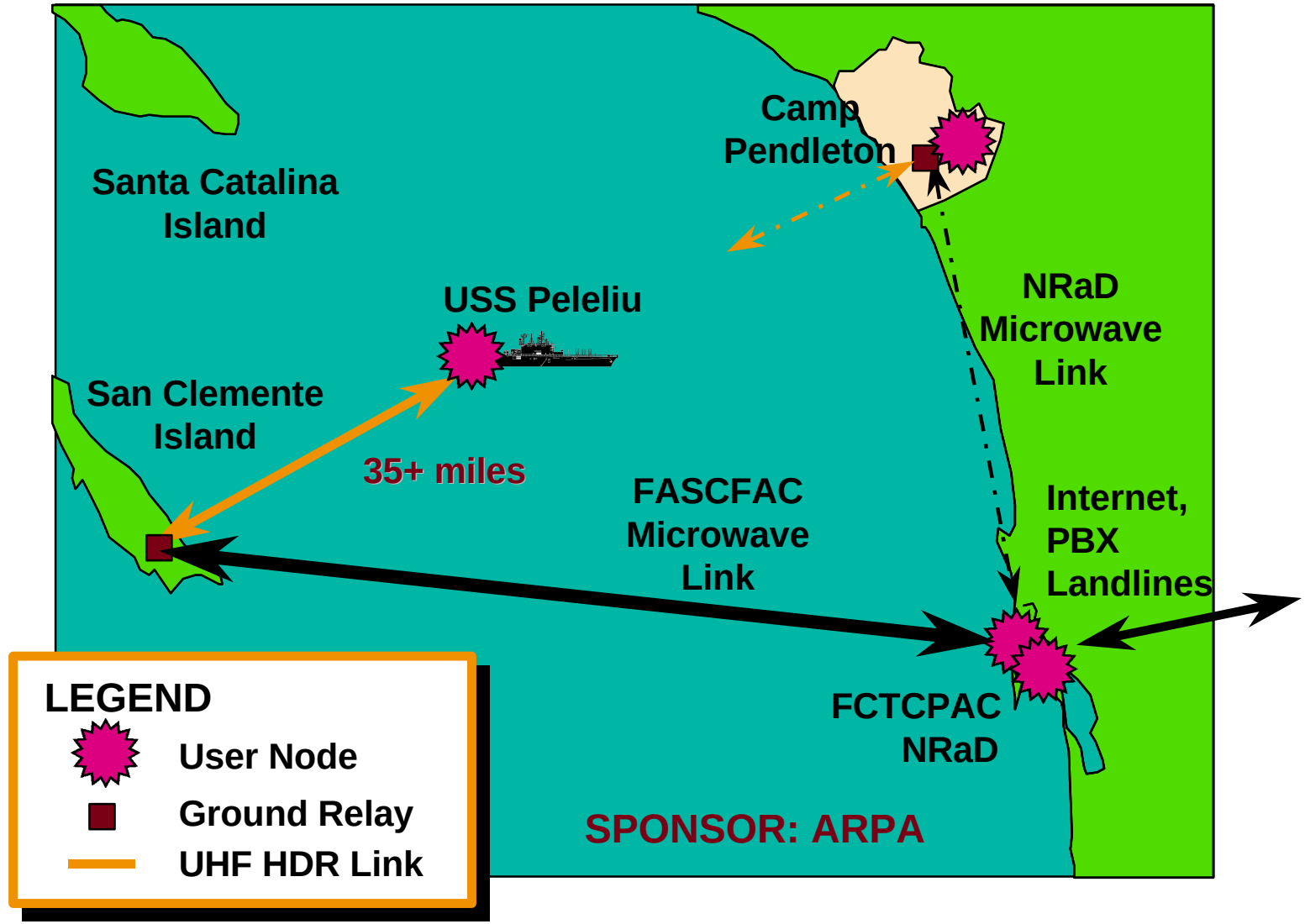
HDR UHF LOS DEMO
Kernel Blitz 95



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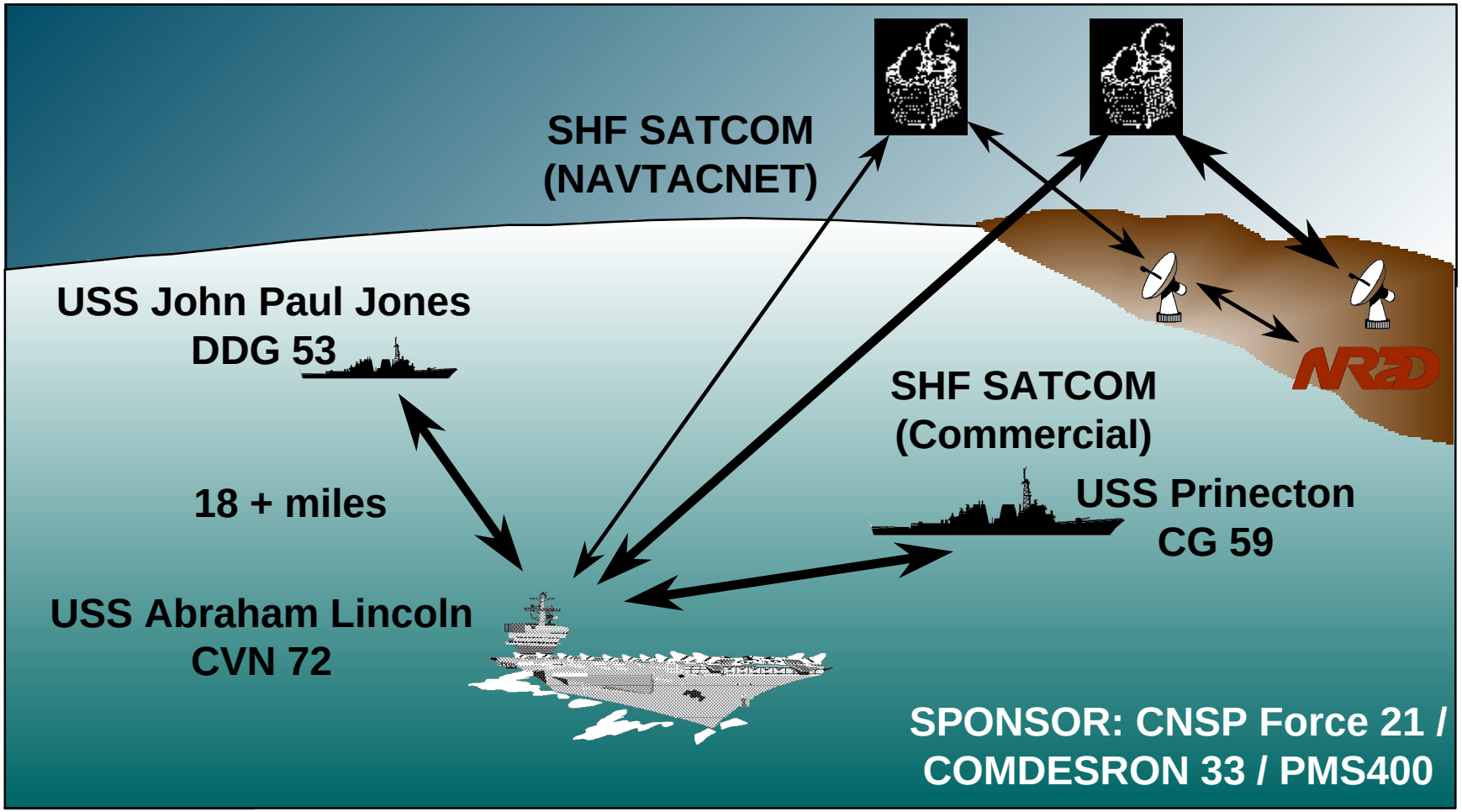
HDR UHF LOS & SATCOM DEMO
Lincoln Battle Group - FY96



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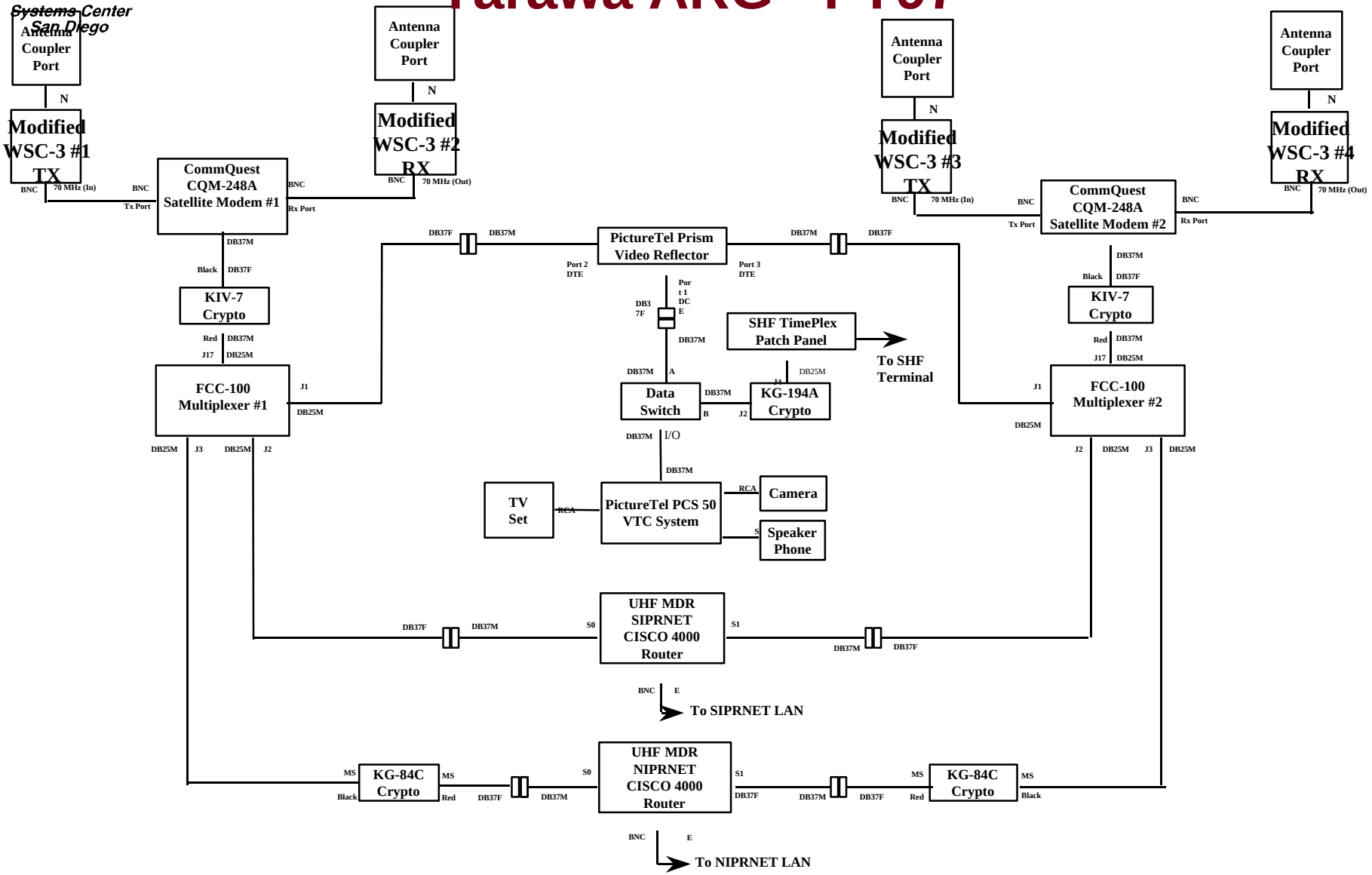
HDR UHF LOS DEMO
Tarawa ARG - FY97



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RF Media Access Control
point-to-multipoint

	Frame 1							Frame 2						
	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7	slot 1	slot 2	slot 3	slot 4	slot 5	slot 6	slot 7
f1	1→2	1→3	1→4	1→5	1→6	1→7	1→8	1→2	1→3	1→4	1→5	1→6	1→7	1→8
f2	2→1	2→3	2→4	2→5	2→6	2→7	2→8	2→1	2→3	2→4	2→5	2→6	2→7	2→8
f3	3→1	3→2	3→4	3→5	3→6	3→7	3→8	3→1	3→2	3→4	3→5	3→6	3→7	3→8
f4	4→1	4→2	4→3	4→5	4→6	4→7	4→8	4→1	4→2	4→3	4→5	4→6	4→7	4→8
f5	5→1	5→2	5→3	5→4	5→6	5→7	5→8	5→1	5→2	5→3	5→4	5→6	5→7	5→8
f6	6→1	6→2	6→3	6→4	6→5	6→7	6→8	6→1	6→2	6→3	6→4	6→5	6→7	6→8
f7	7→1	7→2	7→3	7→4	7→5	7→6	7→8	7→1	7→2	7→3	7→4	7→5	7→6	7→8
f8	8→1	8→2	8→3	8→4	8→5	8→6	8→7	8→1	8→2	8→3	8→4	8→5	8→6	8→7

Table 1. Time Slot vs. Carrier Frequency

*need 8 frequencies, each 8x600 KHz=4.8 MHz

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RF Media Access Control
multi-carrier DAMA

	Frame 1								Frame 2							
f1	F	R	R	2→5	4→6	3→7	2→7		F	R	R	4→5	4→6	3→7	5→4	
f2	X	R	R	1→2	1→2	1→2	1→2		X	R	R	1→2	1→2	1→2	1→2	
f3	X	R	R	3→6	2→8	4→5	3→8		X	R	R	3→8	3→6	5→8	4→1	
f4	X	R	R	5→1	5→1	5→1	5→1		X	R	R	2→3	2→3	2→3	2→3	

Table 2. Time Slot vs. Carrier Frequency

* Variable time slot => 1536 kbps/frame
* Bandwidth on demand !!

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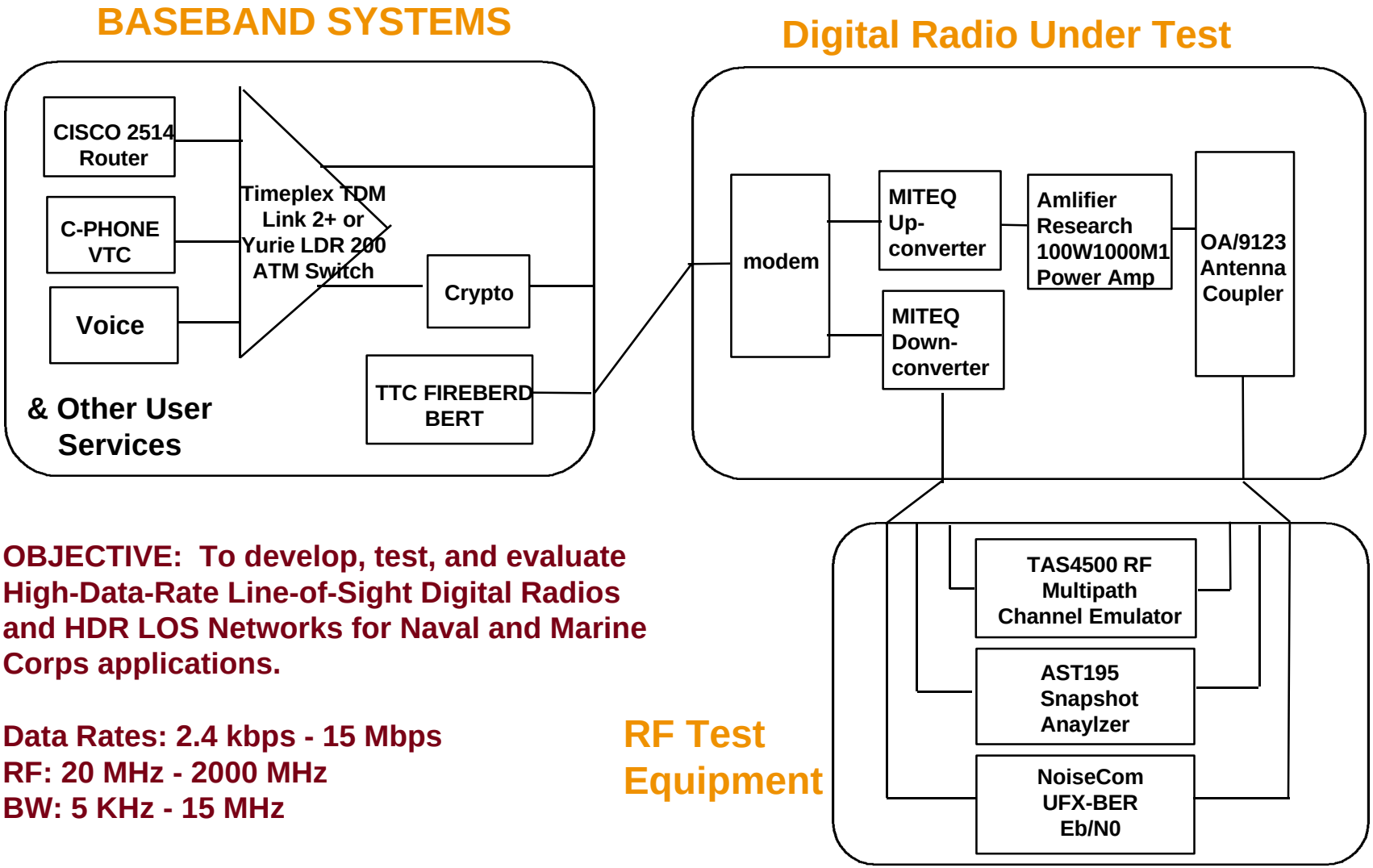
HDR LOS Digital Radio

Multipath Fading Test Setup



OBJECTIVE: To develop, test, and evaluate High-Data-Rate Line-of-Sight Digital Radios and HDR LOS Networks for Naval and Marine Corps applications.

Data Rates: 2.4 kbps - 15 Mbps
RF: 20 MHz - 2000 MHz
BW: 5 KHz - 15 MHz

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HDR LOS Modem: Technical Objectives - Why?

- HDR Wireless Network requires at least 3 separate links from/to each mobile ship/platform
- omni antennas to required reduce costs, networking complexity (e.g. AS1735/AS390/...)
- low carrier frequencies to reduce propagation losses ($L=20\log(f_c) + 20\log(d) - 20\log(C/4\pi)$ dB) and fade rates ($F_{max}=f_c(1-v/c)$)
- UHF 225-400 MHz reasonable (no radars, NATO band I, low environmental noise)
- BUT ... lots of AM/FM Voice & LDR data users results in EMC problems and possible interference
- synergy w/ MDR UHF SATCOM program (64 kbps / 25 KHz Channel ... 0.8*25=20ksps)

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HDR LOS Modem: Technical Objectives - Why?

Ship-to-Ship Link at 400 MHz

Ship-to-ship Range (nmi)			10 nmi	15nmi	20nmi	25nmi	30nmi	
Tx Power (dBW)			20	20	20	20	20	
Tx cable,antenna,…(dB)			-4	-4	-4	-4	-4	
Propagation loss (dB)			-117	-125	-133	-140	-147	
Rx cable,antenna,…(dB)			-4	-4	-4	-4	-4	
Rx Noise Figure (dB)								8
Rx Antenna Temp (K								300
Rx System Temp (K)								1840
Noise Spectral Density (dBW/Hz)			-196	-196	-196	-196	-196	
C/No (dB-Hz)			91	83	75	68	61	
Data Rate	(kbps)	(dB-bps)	Max. Av. Eb/No Available (dB)					
	4608	67	24	16	8	1	-6	
	1536	62	29	21	13	6	-1	
	576	58	33	25	17	10	3	
	64	48	43	35	27	20	13	
			10 nmi	15nmi	20nmi	25nmi	30nmi	

Max. Av. Eb/No Available

Bandwidth Efficiency (bps/Hz)	Shannon Limit AWGN Eb/No (dB)	Waveform	Eb/No Required for BER=10-6 Theory	Typical	Typical + 5dB Margin
1	0.2	BPSK	10.5	12.0	17.0
		QPSK rate 1/2	5.5	6.0	11.0
2	1.7	QPSK	10.5	12.5	17.5
		8-PSK rate 2/3	7.5	9.5	14.5
3	3.5	8-PSK	14.0	16.0	21.0
		16-PSK rate 3/4	11.5	14.5	19.5
4	5.5	16-PSK	18.0	21.0	26.0

Min. Eb/No Required

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HDR LOS Modem:
Technical Objectives - Why?
Channel Bandwidth versus Data Rates

	Symbol	Channel	BW eff = 3.2 bps/sps		BW eff = 1.6 bps/sps		BW eff = 0.8 bps/sps	
	Rate	Bandwidth	Data Rate	Number	Data Rate	Number	Data Rate	Number
"n"	(ksps)	(KHz)	(kbps)	of DS0s	(kbps)	of DS0s	(kbps)	of DS0s
1	20	25	64	1	32	0.5	16	0.25
2	40	50	128	2	64	1	32	0.5
8	160	200	512	8	256	4	128	2
9	180	225	576	9	288	4.5	144	2.25
24	480	600	1536	24	768	12	384	6
40	800	1000	2560	40	1280	20	640	10
48	960	1200	3072	48	1536	24	768	12
72	1440	1800	4608	72	2304	36	1152	18
80	1600	2000	5120	80	2560	40	1280	20

Bandwidth Efficiency = Data Rate / Symbol Rate

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Transistion into NAVY SLICE and/or DoD JPMCS

- Navy and DoD can not afford new or old stove-pipe systems
- All developments under this program will be transistioned into the Navy's SLICE Radio and/or the DoD's JPMCS as soon as possible
- Modular Design (Hardware & Software)
  - HDR LOS Modem: 6U VME
  - RF mixers: 6U VME
  - HPA, Coupler, Antenna separate
  - RF MAC: 6U VME modules, C++/C software
  - Interfaces and Control are based on commercial standards and completely documented
  - Multiple vendor support